Civilian Passenger Vehicle Burnover Experimentation

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Abstract

The loss of life of civilians in vehicles during bushfires in Australia has been of concern for several decades. Preventable deaths related to vehicles used in untimely evacuation or travel have occurred with regular frequency. While it is understood that a range of factors can contribute to such fatalities, currently there is insufficient understanding of the subject of vehicle occupant behaviour during a bushfire and clear practices need to be recommended when faced with this situation. In 2006, the federal fire authority and the Australasian Fire Authorities Council (AFAC), working together with CSIRO, sanctioning the document "Guidance for people in vehicles during bushfires"([1]AFAC,2006). This provided clear advice on the most appropriate actions to take if caught in a vehicle during a passing fire front given current understanding. However a number of points of advice were not back by clear scientific observation and there were several uncertainties on protective actions taken by occupants e.g. air conditioning on or off, orientation of car to fire-front, effectiveness seeking protection under woollen blanket? These uncertainties were investigated in full-scale experiments where used cars (generally 10-20 years old) were exposed to simulated burn-over conditions with a Liquid Propane Flame Front Simulator. Key observations are found in the conclusion.

- Using a woollen blanket to shelter under in the front seat of a vehicle reduces exposure to toxic gases, while staying below the height of the windows is effective in protecting against radiation. For air temperature exposure staying below the blanket or as low as possible is the most effective strategy, if present operating an air conditioning system in recirculation mode does reduce temperature exposure without affective under blanket toxic levels.
- The orientation of the car to the fire front significantly influenced internal cabin conditions and ultimate survivability during a burnover event. Facing the front of the car towards the approaching fire was better than side or rear orientation.
- The vehicle should not be parked over dry fine fuels, the low level flame contact from these fuels can quickly cause untenable conditions
- Thermoplastic body parts and the structural design features of a vehicle contribute to the loss of physical integrity of the vehicle envelope. With the more recent model vehicles performing worst.
- Engine operation during the event did not result in a significant change in cabin tenability during the test program. But may improve the chances of vehicle operation after the burnover.
- Direct flame contact from either the passing fire front or burning fuel located in the immediate area surrounding a vehicle will result in a near immediate exceedence of tenability.

Further assessment is needed to test such findings with current model vehicles and utility-type vehicles which would be found in many rural and peri-urban settings and have featured in a number of recorded fatalities.

Key Words

Bushfire, Civilian, Automobile, Burnover, Deaths, Protection, Guidelines

[1] AFAC, 2006. "Guidance for people in vehicles during bushfires". INTERIM POSITION PAPER ON GUIDANCE FOR PEOPLE IN VEHICLES DURING BUSHFIRES. AUSTRALASIAN FIRE AUTHORITIES COUNCIL

1.0 Introduction

Preventable deaths in vehicles during untimely evacuation or travel in bushfires in Australia has been of concern for several decades. While fatalities occurred prior to the significant 1959 fires, this event marked the start of a trend of increasing fatalities in or near civilian passenger vehicles. The 1965 Longwood fire was the scene of a tragic mass fatality where a family of 7 perished. In the Hobart bushfires of 1967 a total of 53 people perished, of which 26 people were in or near vehicles (civilians and fire fighters)[2]. The Lara bushfires in 1969 saw the loss of 17 civilian lives where vehicles were involved. On Ash Wednesday in 1983, in Victoria alone 16 civilian lives were lost in circumstances where vehicles were involved[3]. Between June 2000 and July 2005, at least 4 out of 18 recorded bushfire fatalities were vehicle-related[4] (excluding Canberra 2003 and Eyre Peninsula 2005 fires). Recently, 9 people have lost their lives in the Eyre Peninsula fires in South Australia, 8 of which where found in or near their vehicles. Along with the two fatalities in the 2006 Grampians fires, these alarming figures highlight the need for strategies to prevent such unnecessary loss of life.

While it is considered that a range of factors will contribute to civilian vehicle-related bushfire fatalities, there is poor knowledge of vehicle safety/refuge during a bushfire or key protective practices when faced with this situation. The best available knowledge has been presented in a 2006 document by the Australasian Fire Authorities Council (AFAC) "Guidance for people in vehicles during bushfires". These guidelines represent the best current advice to the Australian public when faced with a bushfire-front in a civilian passenger vehicle. The information provided in this guide was largely based on a collation of advice and recommendations given by state fire authorities and recommendations in the limited literature available from respected fire researchers such as Cheney, N.P and Budd, G.M

However, uncertainties remain for several specific factors on vehicle status and protective actions taken by occupants e.g. air conditioning on or off, and orientation of car to fire front, seeking protection under woollen blanket. This study was undertaken to reduce such uncertainties and to lead to improved guidelines for survival in vehicles during bushfire burnovers.

2.0 Aims

1. To determine the maximum heat load at which a vehicle typical of a bushfire burnover event in Australia (i.e. late model passenger car) would still retain its integrity and provide a safe haven for its occupants. Assessed using the internal cabin conditions in terms of surface temperatures, air temperatures, internal radiation exposures and air quality assessment.
2. To assess the pros and cons of leaving an engine operating during a burn over, with respect to in-cabin tenability and vehicle function (post-burnover) and flammability (with respect to the fuel system (fuel lines, tank, fuel pump).
3. To assess if car orientation with respect to the fire front provides specific protection to occupants.
4. To assess whether the cabin air recirculation system / air conditioning system should be left operating for optimised occupant tenability and survivability.
5. To gain insight into the duration a vehicle occupant is required to withstand burnover conditions, and to observe which signs are reliable for an occupant to determine the most appropriate condition at which to egress the vehicle (linked to the likelihood that egress will occur before tenability limits within the vehicle are reached).
6. To assess the advantage of crouching under a woollen blanket in a specific location within the vehicle interior and/or other common self-protection measures in a burnover situation.

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[2] Loane L.T. & Gould J.S. (1986) Aerial Suppression of Bushfires - cost benefit study for Victoria, CSIRO,
[3] Krusel N. & Petris S. (1999) A study of Civilian Deaths in the 1983 Ash Wednesday Bushfires Victoria, Australia. CFA Community Safety Directorate, Country Fire Authority.
[4] Morton S. (2005). NCIS Database Search, Bushfire and Wildfire Fatalities. Vic Institute of Forensic Medicine.

3.0 Test Method

The testing methods used for the civilian passenger vehicles were adapted from those used in previous CSIRO research on Rural Fire Tanker Design.[5] The methods expose a full-scale vehicle (fully instrumented to measure in-cabin temperature, radiation and air quality) to a Liquid Propane Flame Front Simulator at the NSW Rural Fire Service's Hot Training Centre at Mogo on the New South Wales south coast. The test facility simulates the three phases of a bushfire burnover:
* the approach phase, where radiation loads from the approaching fire are the main threat;
* the flame immersion phase, where heat transfer and ignition may occur by direct flame contact both on the windward, leeward sides and beneath the vehicle; and
* the receding phase, where the bushfire has passed the vehicle and radiant heat loads subside.
The civilian passenger vehicle program used use the flame immersion phase, as it was considered that it would lead to rapid loss of the integrity of the cabin, instead concentrated on determining the maximum radiant heat level and sensitivity to under burn of these vehicles.
Tests were carried out at a number of burnover conditions:

- Test duration was fast (~4 minutes) to simulation a grass fire under high wind conditions or slow (12-15 minutes) to simulating the longest practical high fuel load forest fire.
- Tests were at different peak radiant intensities in the range 10-40 kW/m^2, simulating different separation distance form the main fine fuel load.
- Some tests used additional under body burners for short periods (~1 minute) during burnover to simulate the parking of the vehicle over short dry grass.

4.0 Defining tenable and survivable cabin conditions for air toxics, temperature and radiation exposures.

Air toxics[8] and thermal exposure within the car cabin during fire simulation experiments were based on two criteria described previously by Knight et al. 2001[6]:

- tenability – the occupants will be able to occupy the cabin for the bushfire burnover period without experiencing intolerable irritation, significant loss of alertness, or irreversible health effects
- survivability – the occupants will be able to occupy the cabin for the bushfire burnover period without long term loss of function and consciousness or loss of life.

Tenability is the obvious performance target for vehicles caught in a bushfire, but survivability must be considered as the critical factor in making an assessment of car performance.

Knight et al. (2001) considered that the cabin temperature and radiation survivability levels which could only be endured for less than a minute were:

- Short term radiation direct in the person: limit = 2 kW/m^2
- Short term blast of hot air: temperature limit = 200 degrees Celsius.

Occupants would be expected to abandon a vehicle cabin after experience these levels for 1 minute. Note that research into the circumstances of civilian deaths in burnover events highlights critically that in many cases the occupants leave the vehicles and perish soon after. [6]
Criteria for air toxics concentrations in cabins were also derived and are presented in Brown et al 2003[8].

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[5]Definition of Burn-over Conditions for the testing of Firefighter Tankers. Client Report No. 977 CSIRO Forestry and Forest Products, CSIRO Manufacturing and Infrastructure Technology -c-2003-059.
[6]Krusel N. & Petris S. (1999) A studiy of Civilian Deaths in the 1983 Ash Wednesday Bushfires Victoria, Australia. CFA Community Safety Directorate, Country Fire Authority.
[8]Brown, S.K. et al (2003). Air Toxics Factors and Criteria for Crew Survivability/Tenability in Vehicle Burnover. 21st Annual Conference of the Australian Institute of Occupational Hygienists, "Improving occupational hygiene in smALL business", Dec. 6-10, 2003, Adelaide.

5.0 Measurement of Air Toxics

Car interiors were monitored for air toxics at two locations in all tests:

- seated head height, between the front seats
- below a wool blanket (~30cm above floor) in the front seat well.

During burnover tests, air from the cabin was drawn from these locations to a remote tank from which the following air toxics were sampled (noting a 1.0-1.5 minute delay from cabin conditions) as described in Brown et al 2003[8]:

- Respirable particles (RP, mg/m^3) were measured as particle mass in air using a 90° light-scattering laser diode, calibrated to the respirable fraction of a standard ISO 12103–1 A1 test dust. Fire smoke will have a different calibration response from the test dust (e.g. we have found that tobacco smoke gives approx. double the response of the test dust). The RP criteria used for these experiments were 6 (tenability) and (survivability).
- Carbon monoxide (CO) was monitored using a Q-Trak™ Model 8550/8551 IAQ Monitor (TSI Inc., USA) or a Drager PacIII (Drager), both calibrated with 100ppm CO prior to each day of test. The CO criteria were 100 ppm (tenability) and 1000 ppm (survivability).
- Hydrogen chloride (HCl) and Hydrogen cyanide (HCN) were measured by sampling cabin air directly via openable holes through the cabin body at the front seat height of an occupant. These were collected immediately after flame-out at the end of each test. The tenability criteria were 50 ppm (HCl) and 45 ppm (HCN) and the survivability criteria 200 ppm (HCl) and ppm (HCN).

6.0 Temperature measurement of vehicle elements and cabin

Temperatures were measured using 1.5 mm Type 'K' MIMS thermocouples. Thermocouple wires were held in position with self-tapping screws and bent to create a positive pressure between the first 10mm if the thermocouple wire and the surface to be measured. A heat transfer compound was applied to the space between the thermocouple wire and the measured surface, except when glass surface temperatures were being measured.

7.0 Radiation measurement

Heat flux was measured using water-cooled Schmidt Boelter total heat flux meters, with a sensing range of 0 to 100 kW/m^2. The total heat flux measured consisted of both radiative and convective heat. Two heat flux meters mounted beside the vehicle on masts facing horizontally towards the fire in a horizontal and vertical (skyward) plane. Two heat flux meters were mounted internally, one below window height and one above. The orientation of the test vehicle to the flame front determined if these radiometers faced the front windscreen or the side window. The output from the external radiometers was used to relay data to the simulator controller, which then adjusted the control valves pre- and post-burner operation to enable matching of the measured radiation to the predetermined radiation curve for each bushfire burnover scenario.

8.0 Test Specimens (All vehicles were used cars in operable condition, as described below).

Table 1. Test Vehicles

Car	Year	Colour	Bumpers	Door handle	vent covers	Floor	Seats	Door trim
Mazda 323	1983	white	Thermo plastic*	metal	thermo-plastic	carpet/ wadding	all vinyl	vinyl
Toyota Corolla	1984	red	thermo-plastic*	thermo-plastic	thermo-plastic	carpet/ wadding	fabric/vinyl	vinyl
Mitsubishi Magna	1994	white	thermo-plastic*	Plastic (non-softening)	none visible	carpet/ wadding	all fabric	vinyl
Holden Camira		white	thermo-plastic*	metal	thermo-plastic	carpet/ wadding	fabric/vinyl	vinyl
Toyota Corolla	1982	white	thermo-plastic*	thermo-plastic	thermo-plastic	carpet/ wadding	fabric/vinyl	vinyl

* thermoplastic components can soften, distort and flow under high heat loads

9.0 Results

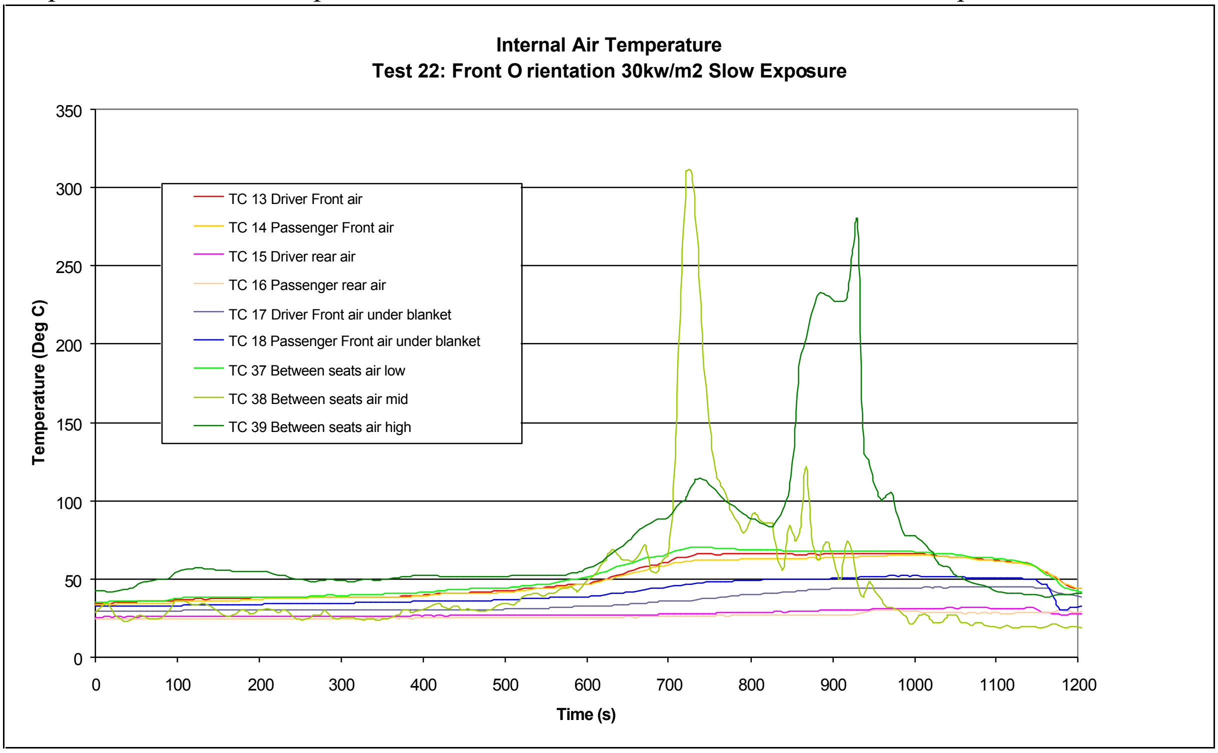
Table 2: Summary of Results

Mazda 323

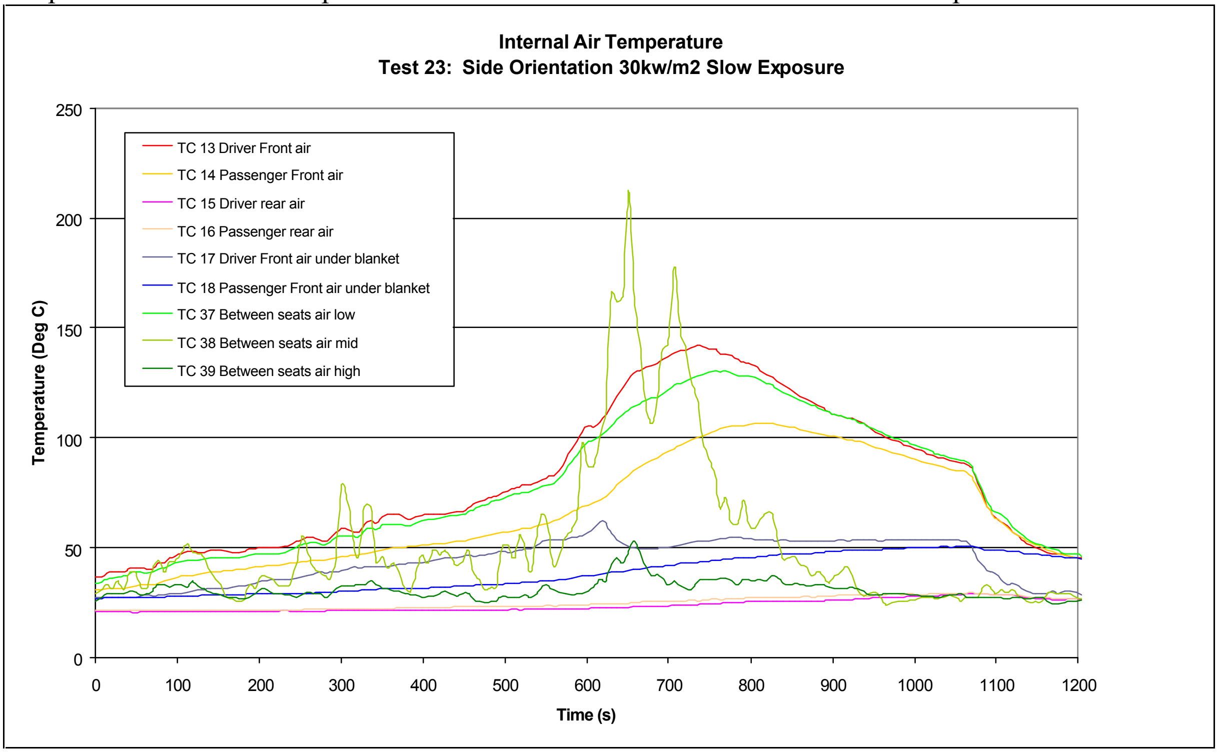
car	**Test**	**Description**	**Radiant heat (inside below window) Max**	**Temperature (inside above blanket, TC 38 between seats mid) Max**	**Air toxic fail time tenability (min)**	
					Under blanket	**Above blanket**
Mazada 323	1	Side 10kw Fast	**0.5 kW/m^2**	**50 C (7.7 min)**	**5.3 min**	**2.7 min**
	2	Side 10kw Fast (repeat)	**0.5 kW/m^2**	**51.7 C (7.8 min)**	**Pass**	**Pass**
	3	Side 10kw Slow	**0.5 kW/m^2**	**68.2 (12.9 min)**	**11.5 min**	**9.8 min**
	4	Side 10kw Slow underburn	**0.5 kW/m^2**	**76.2C (12.2 min)**	**10.3 min**	**8.2 min**
	5	Side 15kw Slow	**0.5 kW/m^2**	**81.4 C (12.3 min)**	**11.3 min**	**9.7 min**
	6	Side 15kw Slow underburn	**0.5 kW/m^2**	**86 C (13.3 min)**	**10.0 min**	**8.8 min**
	7	Front 10kw Slow	**0.5 kW/m^2**	**57.6 C (14.1 min)**	**Pass**	**Pass**
	8	Front 15kw Slow	**0.5 kW/m^2**	**63.3 C (12.5 min)**	**Pass**	**Pass**
	9	Front 15kw Slow Repeat	**0.66 kW/m^2**	**65.5 C (15.7 min)**	**Pass**	**Pass**
	10	Front 15kw Slow Repeat2	**0.5 kW/m^2**	**69.4 C (15.3 min)**	**Pass**	**13.5 min**
	11	Front 20kw Slow	**0.5 kW/m^2**	**72.6 C (11.2 min)**	**Pass**	**10.3 min**
	12	Front 30kw Slow	**0.5 kW/m^2**	**74.4 C (14.5 min)**	**Pass**	**10.5 min**
	13	Front 35kw Slow	**0.5 kW/m^2**	**73.9 C (17.5 min)**	**12.8 min**	**12.8 min**
	14	Back 20kw Slow	**0.5 kW/m^2**	**65.4 C (14.6 min)**	**12.1 min**	**10.8 min**
	15	Back 30kw Slow	**0.5 kW/m^2**	**90.4 C (14.5 min)**	**11.7 min**	**11.2 min**
	16	Back 40kw+ Slow	**0.5 kW/m^2**	**267.4 C (12 min)**	**11.0 min**	**10.5 min**
Red Corrolla	17	Side 15 kw, Slow Fan off	**0.5 kW/m^2**	**92 c (11.6 min)**	**11.8 min**	**8.9 min**
	18	Side 15 kw, Slow Fan on	**0.9 kW/m^2**	**99.3 C (12.7 min)**	**Pass**	**10.0 min**
	19	Side 20kw, Slow Fan on	**1.7 kW/m^2**	**117 C (11.2 min)**	**11.4 min**	**9.2 min**
	20	Side 20kw, Slow Fans off	**1.3 kW/m^2**	**128C (13.5 min)**	**11.7 min**	**10.6 min**
	22	Front 30kw,slow eng & fan off	**0.2 kW/m^2**	**311 C (12.1 min)**	**14.5 min**	**14.8 min**
	23	Side 30kw,slow eng & fans off	**0.15 kW/m^2**	**212 C (11 min)**	**9.8 min**	**8.7 min**
	24	Side 40kw,Slow,eng & fan off	**0.9 kW/m^2**	**312.4 (11.5 min)**	**11.5 min**	**10.7 min**
Magna	21	Side 30kw slow eng on fans off	**0.9 kW/m^2**	**215 C (16.5 min)**	**NA**	**NA**
White Camira	25	Side 20kw,slow,eng on,fans off	**0.18 kW/m^2**	**47.6 (17.2 min)**	**11.7 min**	**9.6 min**
	26	20kw, Side,slow,eng on fans off under-burn on 1 min	**0.18 kW/m^2**	**63.5 C (13 min)**	**10.9 min**	**10.0 min**
	27	20kw, Side,slow,eng on fans off under-burn on 1 min	**Test aborted**	**Test aborted**	**Test aborted**	**Test aborted**
	28	0kw, Side,slow,eng on fans off under-burn on 5 min	**0.028 kW/m^2**	**43. 3 C (1.8 min)**	**1.5 min**	**1.3 min**
	29	20kw, Side,slow,eng on fans off under-burn on 1 min	**0.25 kW/m^2**	**47.6 (12.48 min)**	**Not measured**	**Not measured**
	30	20kw, Front,slow,eng on fans off under-burn on 1 min	**Test aborted**	**Test aborted**	**Not measured**	**Not measured**
	31	30kw, Front,slow,eng on fans off under-burn on 1 min	**0.1 kW/m^2**	**40.8 a 16.1**	**Not measured**	**Not measured**
	32	20kw, front,slow,eng on fans off under-burn on 1 min	**0.1 kW/m^2**	**38 a 16.6**	**Not measured**	**Not measured**

Results in Red highlight test where tenability has been exceeded

Graph 1: Internal Air Temperature Test 22: Front Orientation 30kW/m2 Slow Exposure



Graph 2 : Internal Air Temperature Test 22: Side Orientation 30kW/m2 Slow Exposure



Conclusions

- Tenability due to toxic gas exposure was reached before thermal limits in all cases for regions below the window level. Radiant heat levels at the window level quickly exceed the 2kW/m2 limit, with side and rear windows allowing approximately 30% of the radiant heat through and front windscreens 20%.
- Using a woollen blanket to shelter under low in the foot-well of the front or reat seat of a vehicle should reduce exposure to toxic gases (a 2 to 3 fold reduction observed in tests), reduce exposure to radiation and to high temperatures during a bushfire burnover. Temperature measurements from all tests indicated significantly reduced temperatures under the woollen blanket compared to air temperatures above the blanket and higher in the cabin. Similarly, air toxic measurements were generally lower under the blanket. These observations appear to have resulted from heat stratification of air within the cabin.
- Respirable particle were the main reason for tenability exceedence, and were lower below blanket, indicating that strategies that reduce RP intake could be considered.
- The orientation of the car to the fire front will have an effect on the internal cabin condition during a burnover event. e.g. those vehicles orientated **front on** to the fire front performed better than those with a side or rear orientation. In terms of toxic, air temperatures and surface temperature in the foot well occupants may seek refuge. In general vehicle orientated front on remained tenable at radiation levels up to 30kW/m2 while side on and rear facing vehicles lost integrity at around 10 to 15 kW/m2.
- The use of an air-conditioner set on re-circulation reduced internal air temperatures while thermal load on the car was low, however did not significantly alter the peak temperatures reached when compared to a vehicle subjected to the same exposure without the presence or a functioning air conditioner. Under blanket temperature were not significantly influenced by the air conditioning system. Toxic gas exposure for occupants sheltering below blankets in these vehicles was not significantly affected by the air circulation.
- Direct flame contact from either the passing fire front or burning fuel located in the immediate area surrounding a vehicle will reduce the time that a vehicle cabin with remain tenable. Test 28 where an underburn only treatment was applied the vehicle became untenable within **1.5 min** compared to the average time to air toxic untenability which was 10.2 min. Hence it is critical to maximise distance for forest fuels and to avoid parking over ground with significant fuel load.
- The physical integrity of the cabin envelope must be maintained in order for the vehicle to provide a safe refuge during a burnover event.
- Thermoplastic body parts and the structural design features of a vehicle contribute significantly to the physical integrity of the vehicle being breached. Later model vehicles with plastic under body and wheel well guard quickly lost integrity when exposed to underburn. With burn through occurring via plastic covers between the exterior and internal cabin.
- There was no significant involvement of the cars fuel system in any of the experiments, it is important to note that none of the vehicles exposed had a plastic fuel tank.